



## How can Denmark support wind mapping in Africa ?

Hansen, Jens Carsten; Hahmann, Andrea N.; Mortensen, Niels Gylling; Badger, Jake

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## Third Wind Energy Seminar & WindTalks Africa

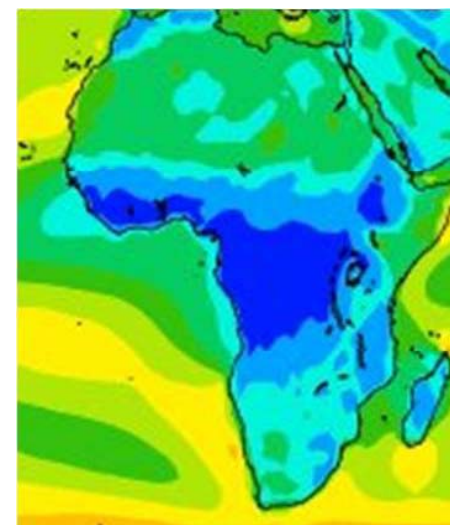
South Africa as a hub and model for wind energy in Africa

### How can Denmark support wind mapping in Africa ?

Jens Carsten Hansen, Andrea Hahmann, Niels G. Mortensen and Jake Badger

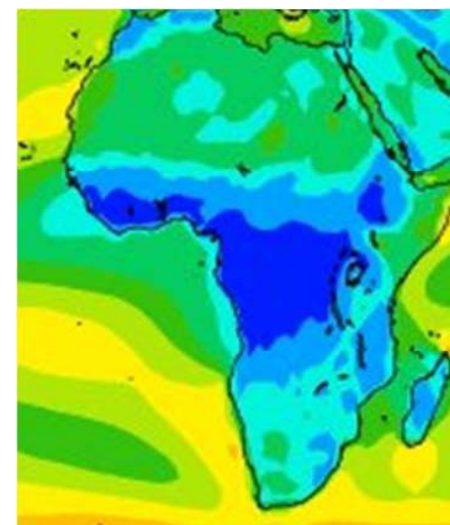
DTU Wind Energy

Technical University of Denmark



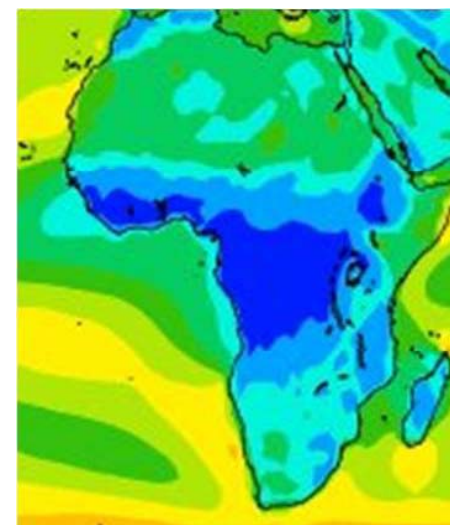
# Outline

- Wind mapping – the facts
- Wind Atlas for South Africa (WASA) – the case
- Africa – challenges and opportunities

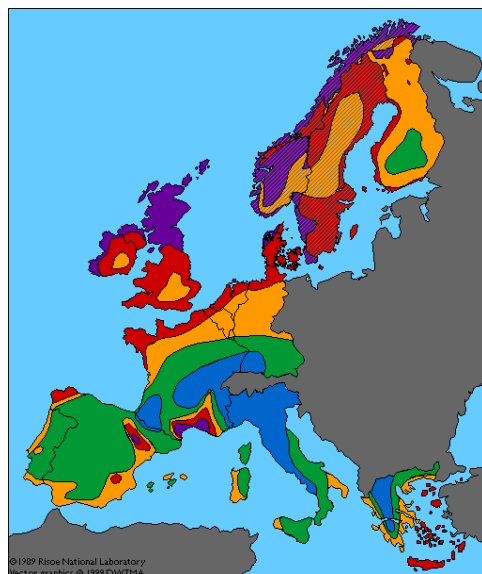


# Outline

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- Africa – challenges and opportunities

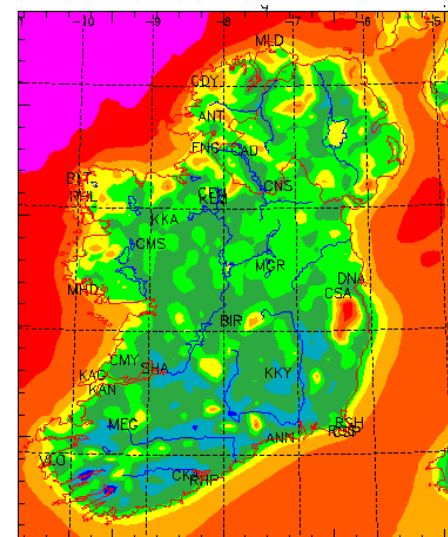


# The Wind Atlas Method



the *observational wind atlas* method and the microscale flow model, WAsP, were conceived in the 80's for the European Wind Atlas

the *numerical wind atlas and* mesoscale model techniques for larger domains, mesoscale effects and long-term wind climates came in the 90's



state-of-the-art wind resource assessment and planning is a combination of microscale and mesoscale modelling verified against measurements

# Why Wind Atlas ?

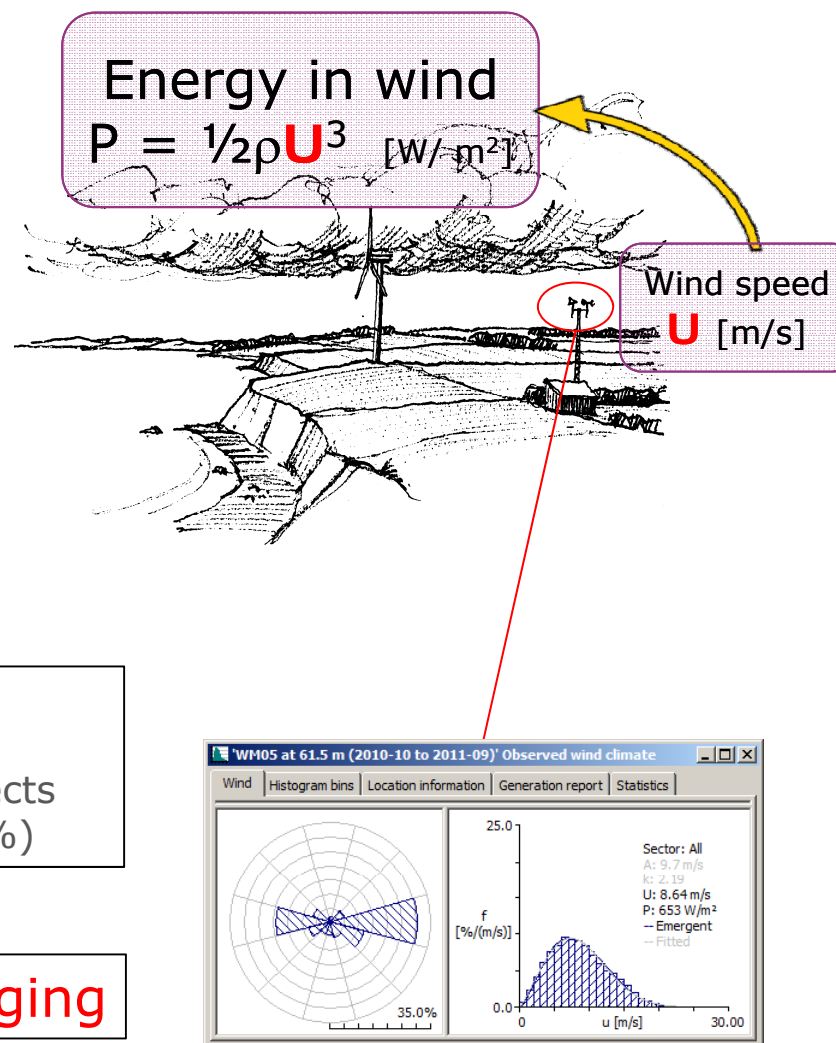
## Wind power economics

- Investment costs
- Operation and maintenance costs
- Electricity production  $\sim$  **Wind resources**
- Turbine lifetime
- Discount rate
- **Environmental benefits**

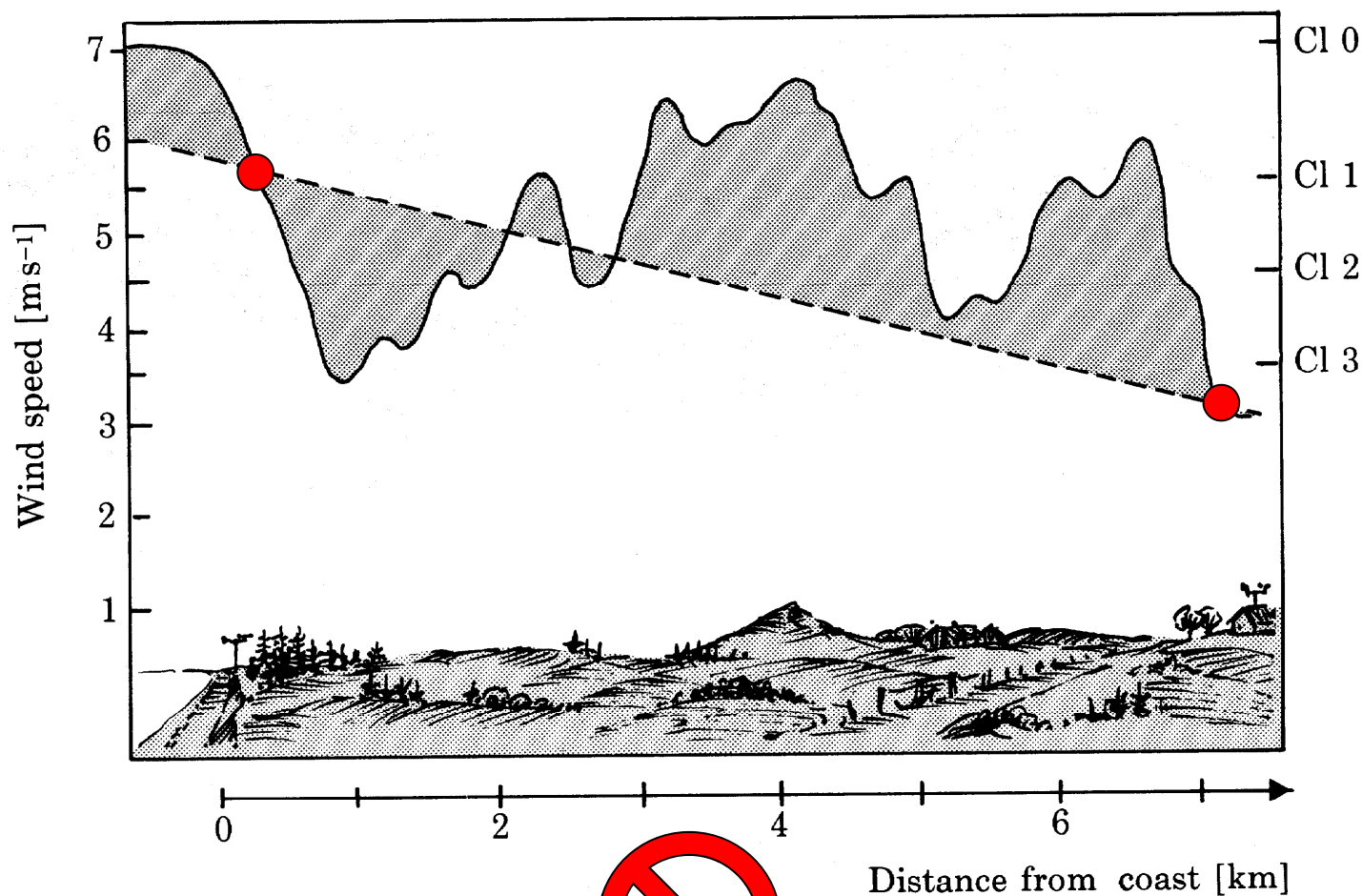
Wind provides the income in cost-benefit

Wind measurements are in one point in space  
 Wind varies significantly across the terrain  
 Spatial distribution needed for planning and projects  
 Accuracy is essential ( $\Delta U$  of 5%  $\rightarrow$   $\Delta P$  of 15%)

**Modelling is necessary and challenging**



# Measurements and Linear interpolation - NO

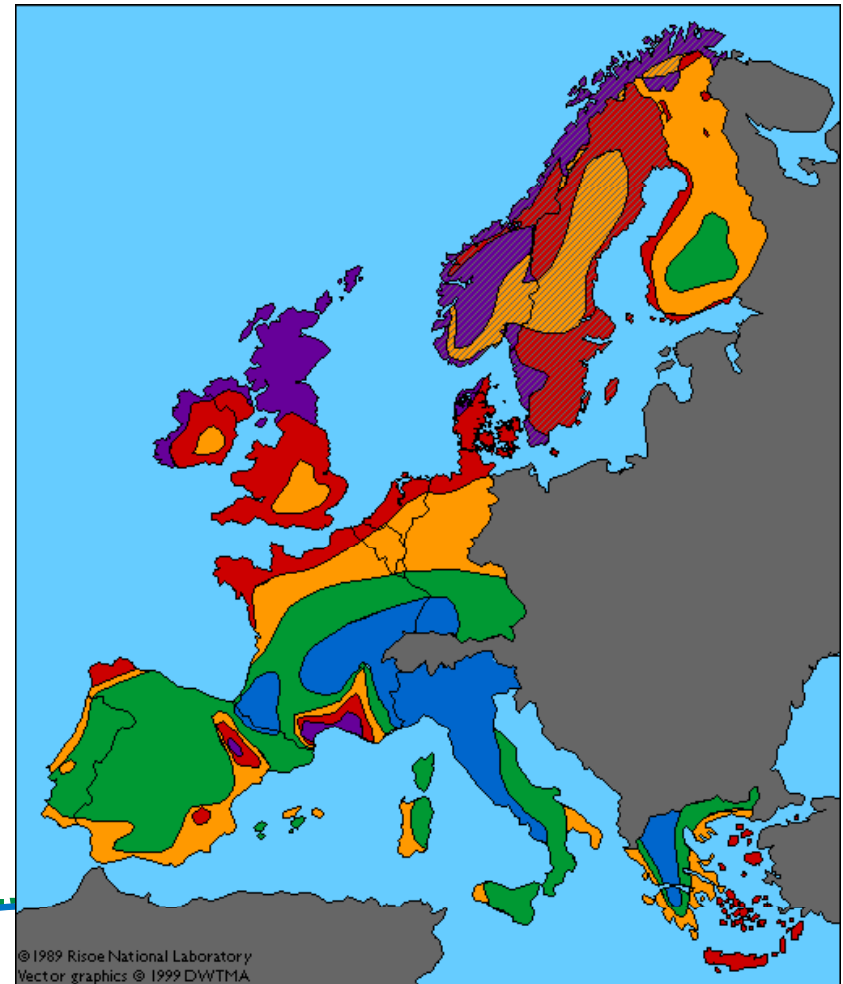
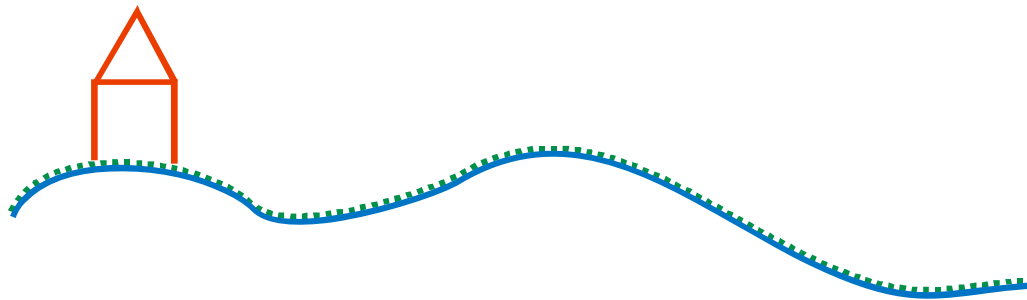


# Microscale modelling, e.g. WAsP

assuming constant wind climate over modelling domain

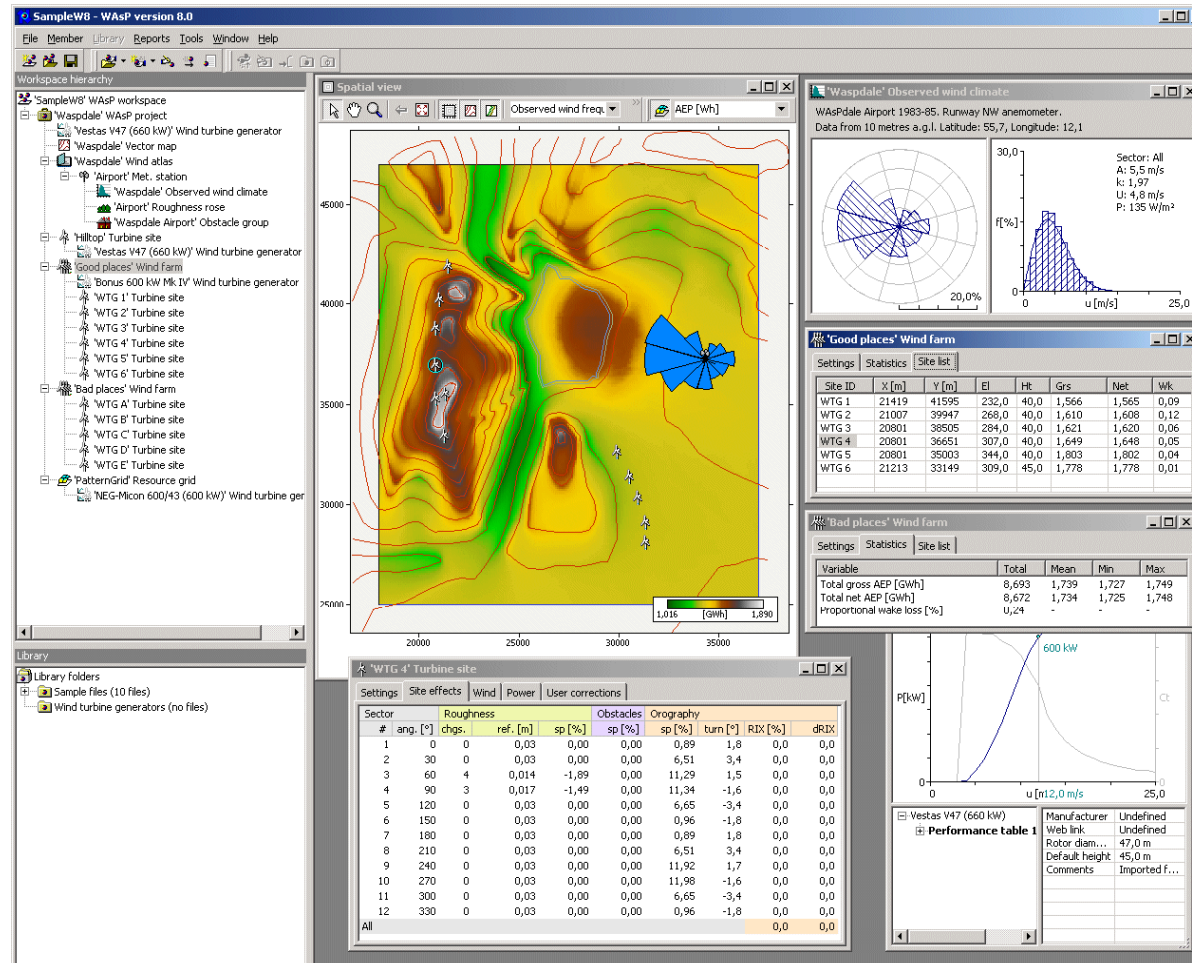


$$\text{WAsP} = \text{ROU} + \text{ORO} + \text{OBST}$$





# WAsP - wind resources, energy production estimation and siting

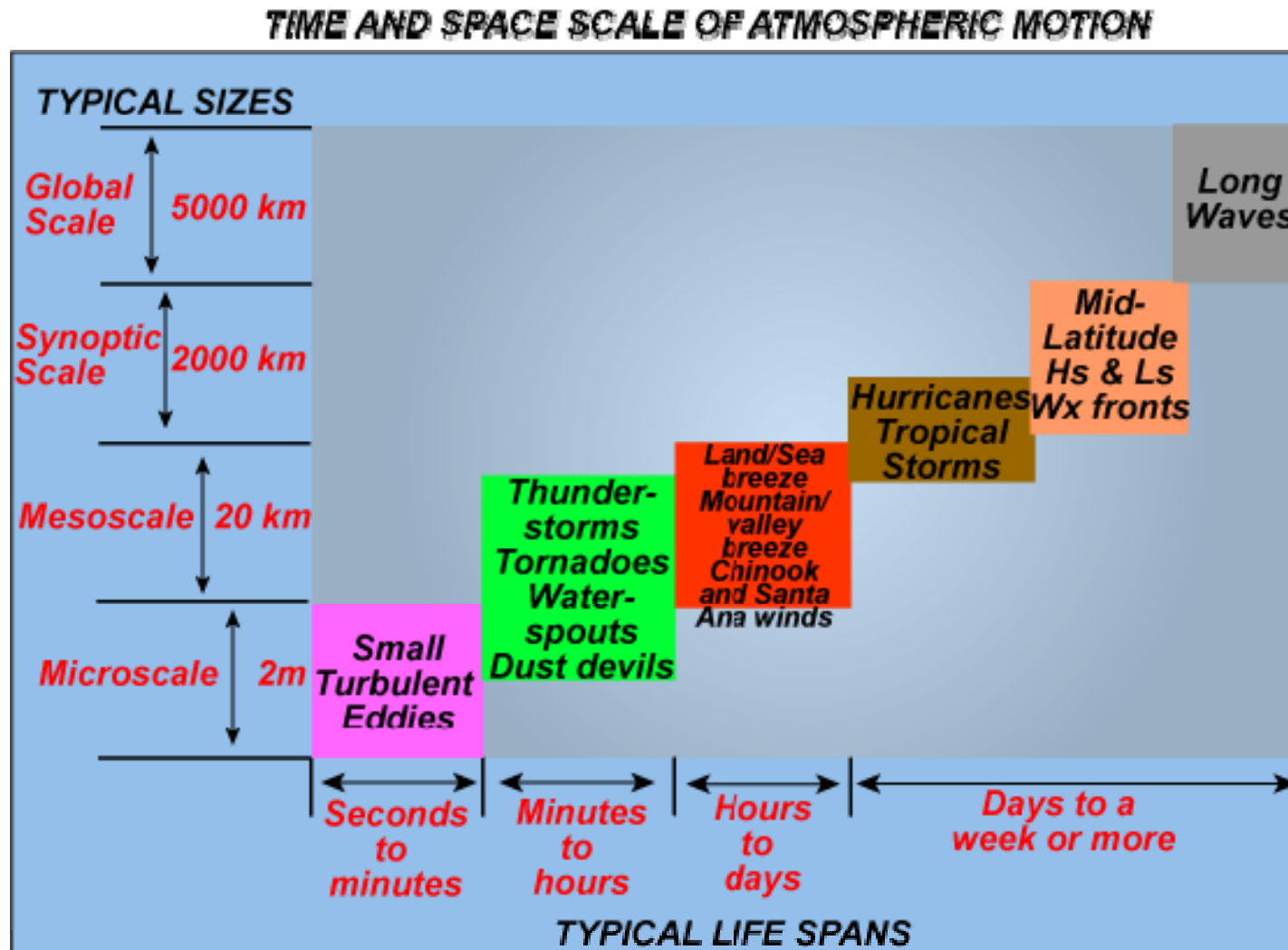


The industry-standard Wind Atlas Analysis and Application Program

More than 3600 users in over 110 countries use WAsP for:

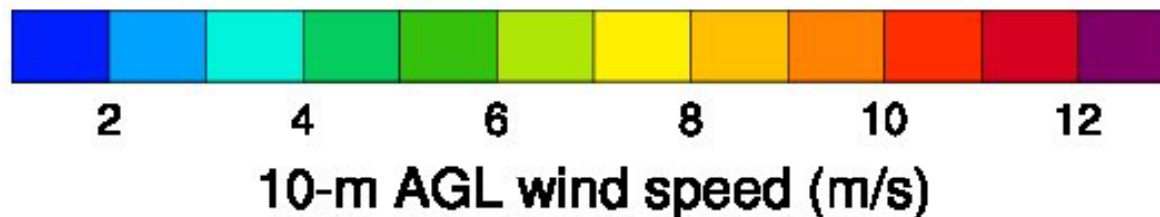
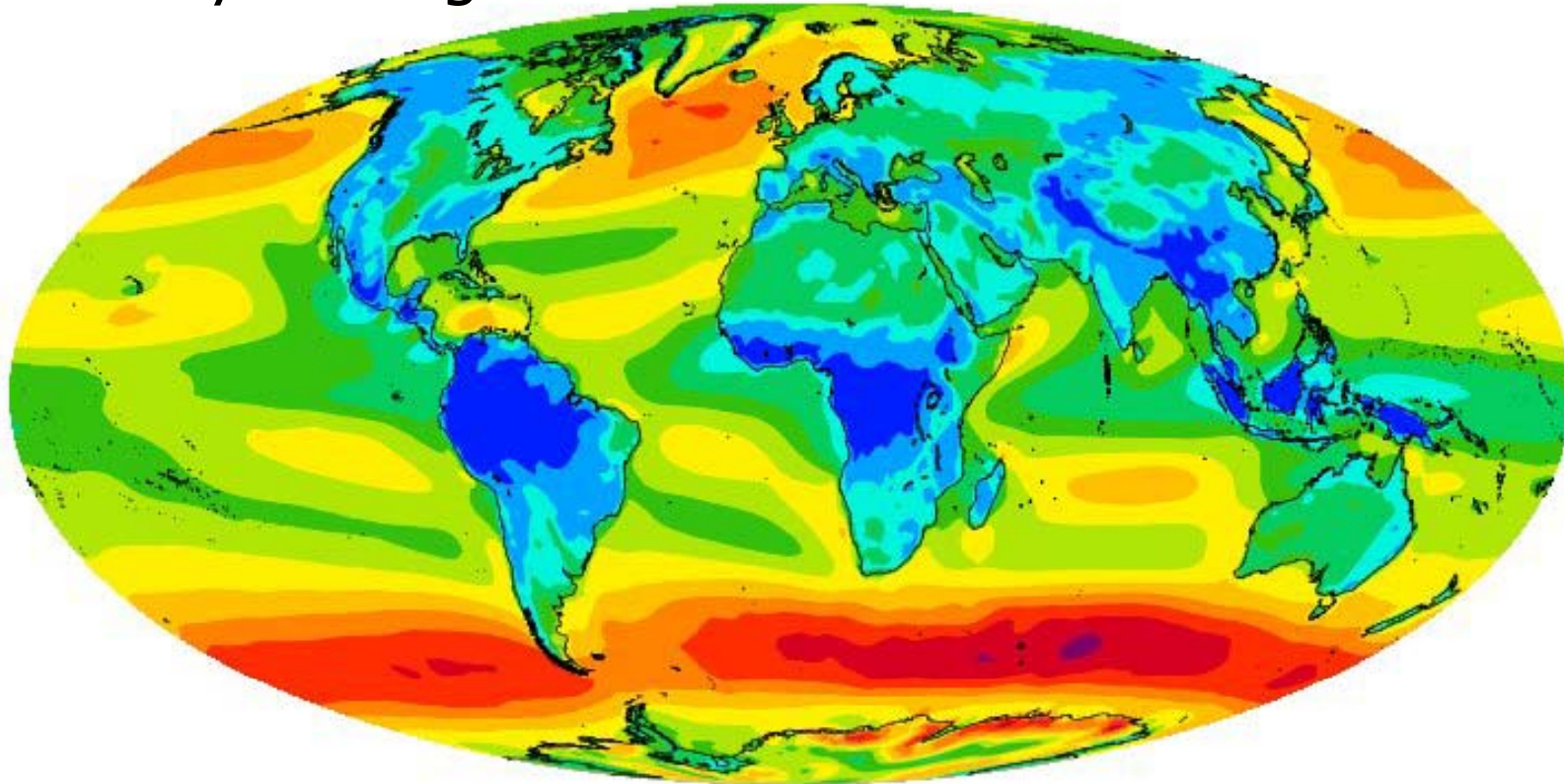
- Wind data analysis
- Map digitisation & editing
- Wind atlas generation
- Wind climate estimation
- Energy production of WTG's
- Micro-siting of wind turbines
- Wind farm production
- Wind farm efficiency
- Wind resource mapping

# However, what about other scales of atmospheric motion ?



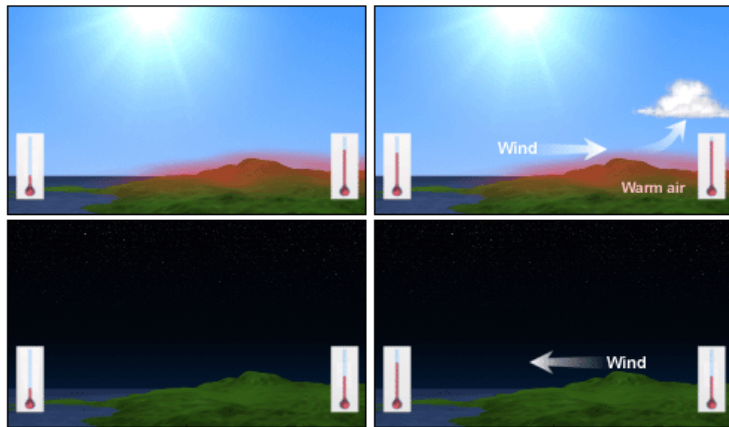
# Global Circulation Models (GCMs)

Annually averaged winds across the world

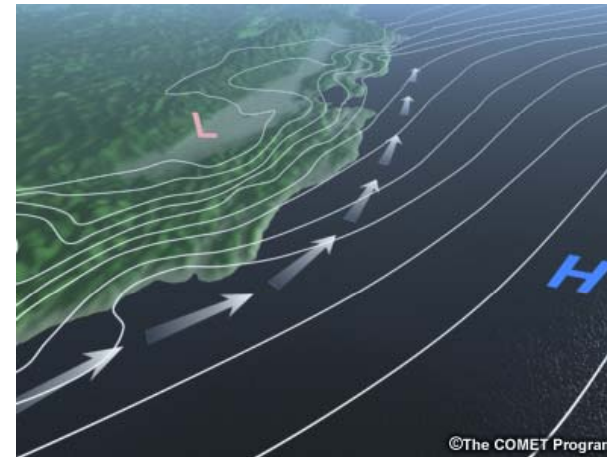




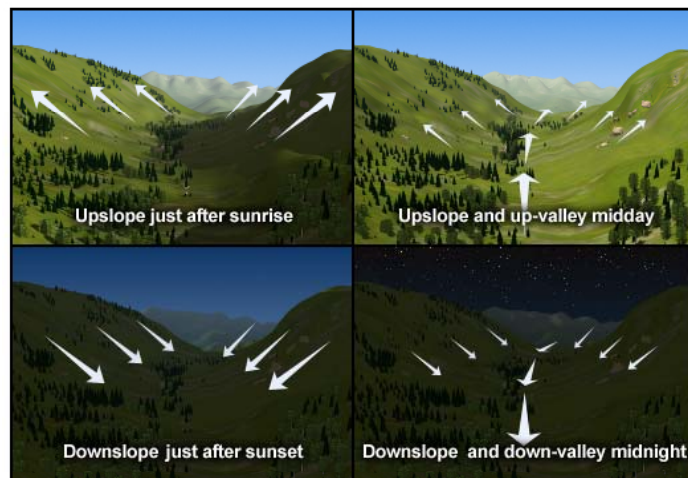
# Mesoscale processes generate and/or modify regional circulation systems



Coastal jet  
sea-land breeze  
©The COMET Program

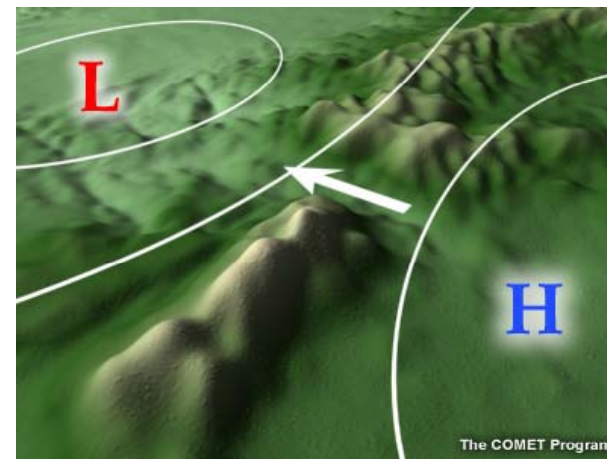


coastal jet



The COMET Program

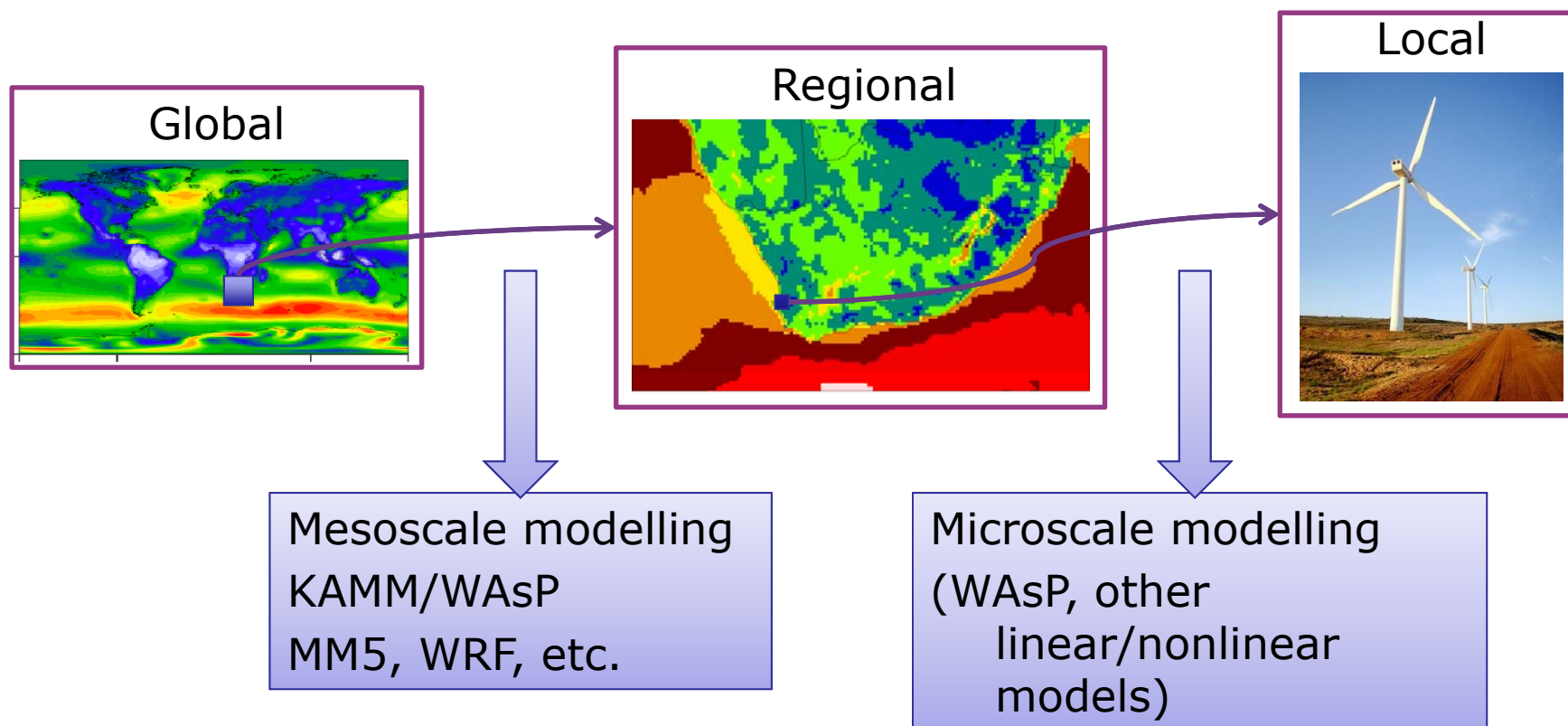
Risø DTU  
National Laboratory for Sustainable Energy



gap flow

# Numerical Wind Atlas

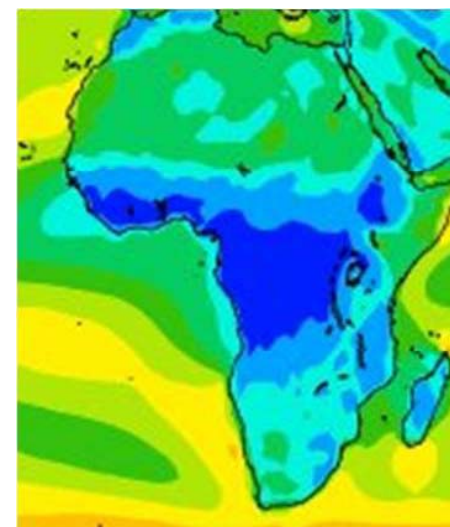
Downscaling from global reanalysis data



**KAMM:** Karlsruhe Atmospheric Mesoscale Model  
**WAsP:** Wind Atlas Analysis and Application microscale model

# Outline

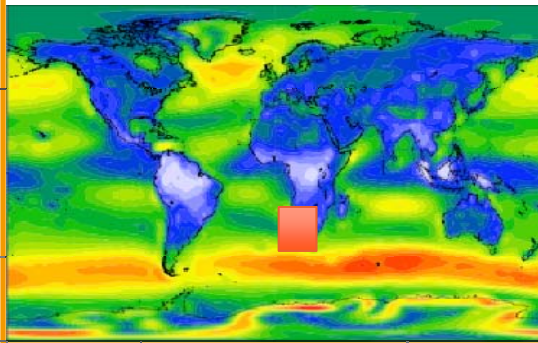
- Wind mapping – the facts
- Wind Atlas for South Africa (WASA) – the case
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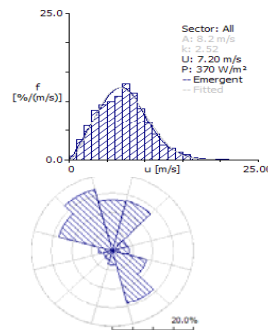
# Wind Atlas for South Africa (WASA) project overview



Global



Measurements

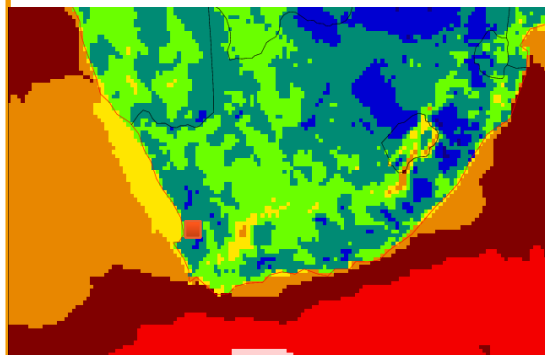


wind farm



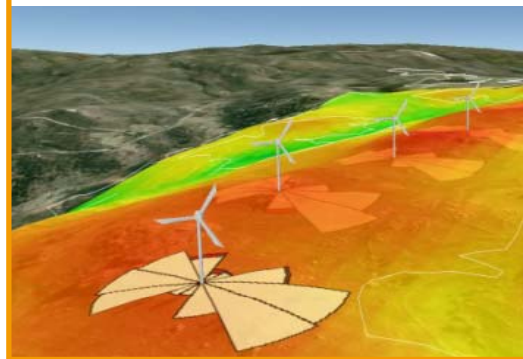
Mesoscale modeling

Regional wind climate



Microscale modeling

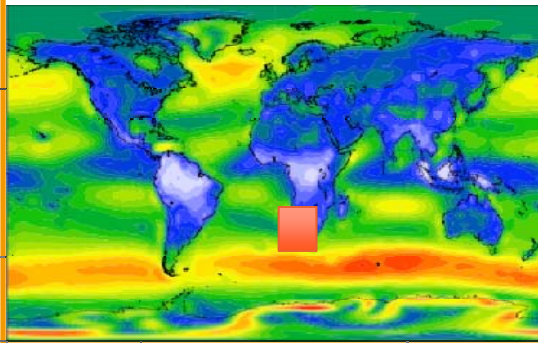
Local wind



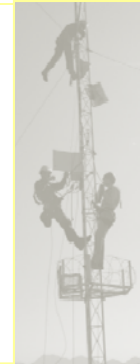
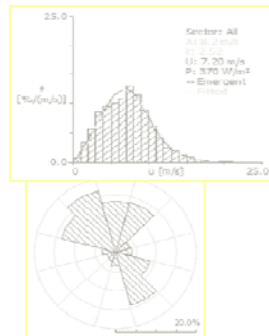


# Wind Atlas for South Africa (WASA)

Global



Measurements



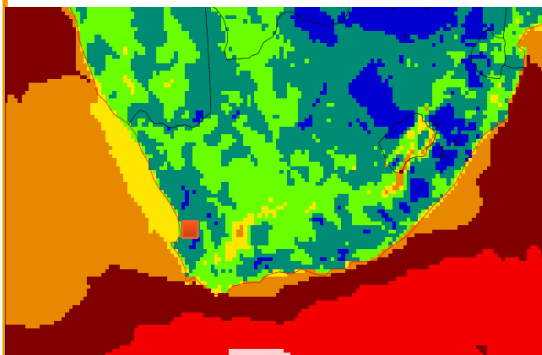
wind farm



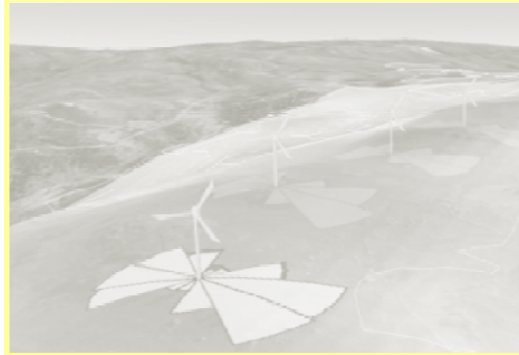
Mesoscale modeling

Microscale modeling

Regional wind climate



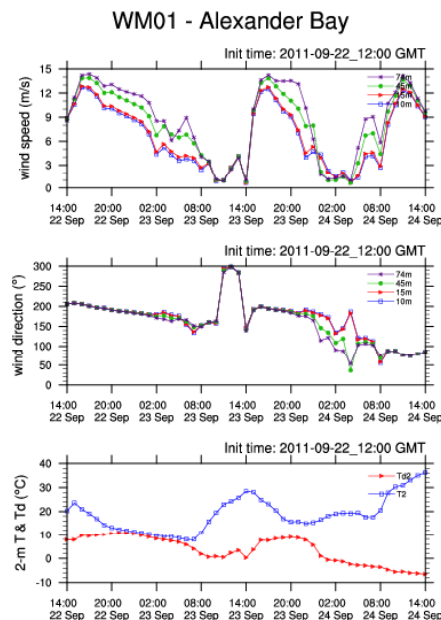
Local wind



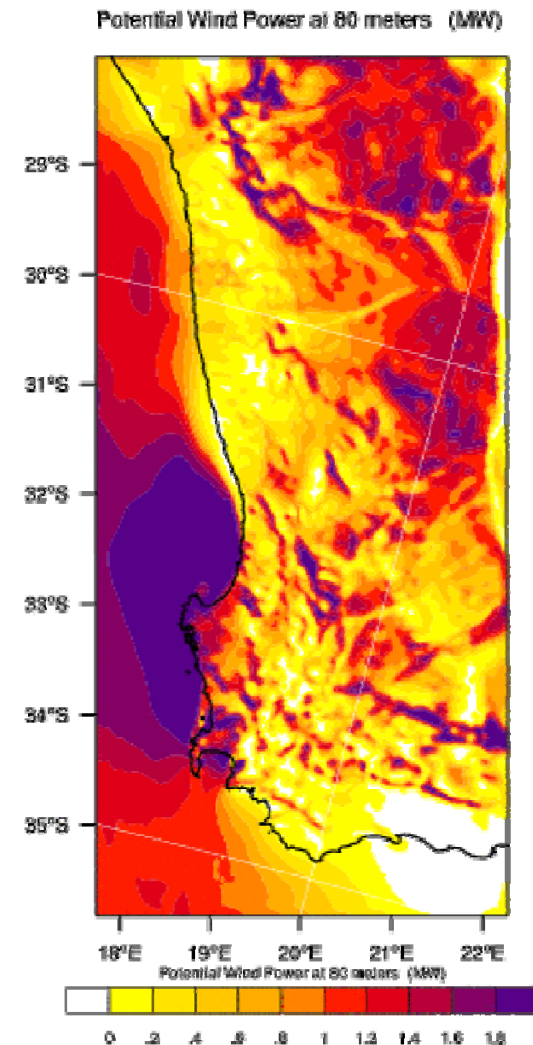
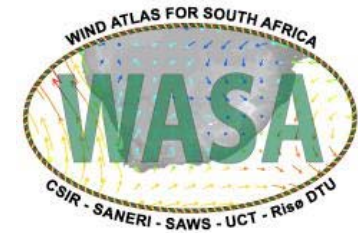


# Mesoscale modelling

- Daily wind forecasts to understand wind regimes. WRF wind forecasts: <http://veaonline.risoe.dk/wasa>
- Setup and run of mesoscale models
- Verification against data from the 10 WASA met stations
- Release of first verified version in February 2012



Init: 2011-11-29\_12:00:00  
Valid: 2011-11-29\_18:00:00



# First KAMM Mesoscale Modelling

## 30-year mean mesoscale wind speed at 100 m



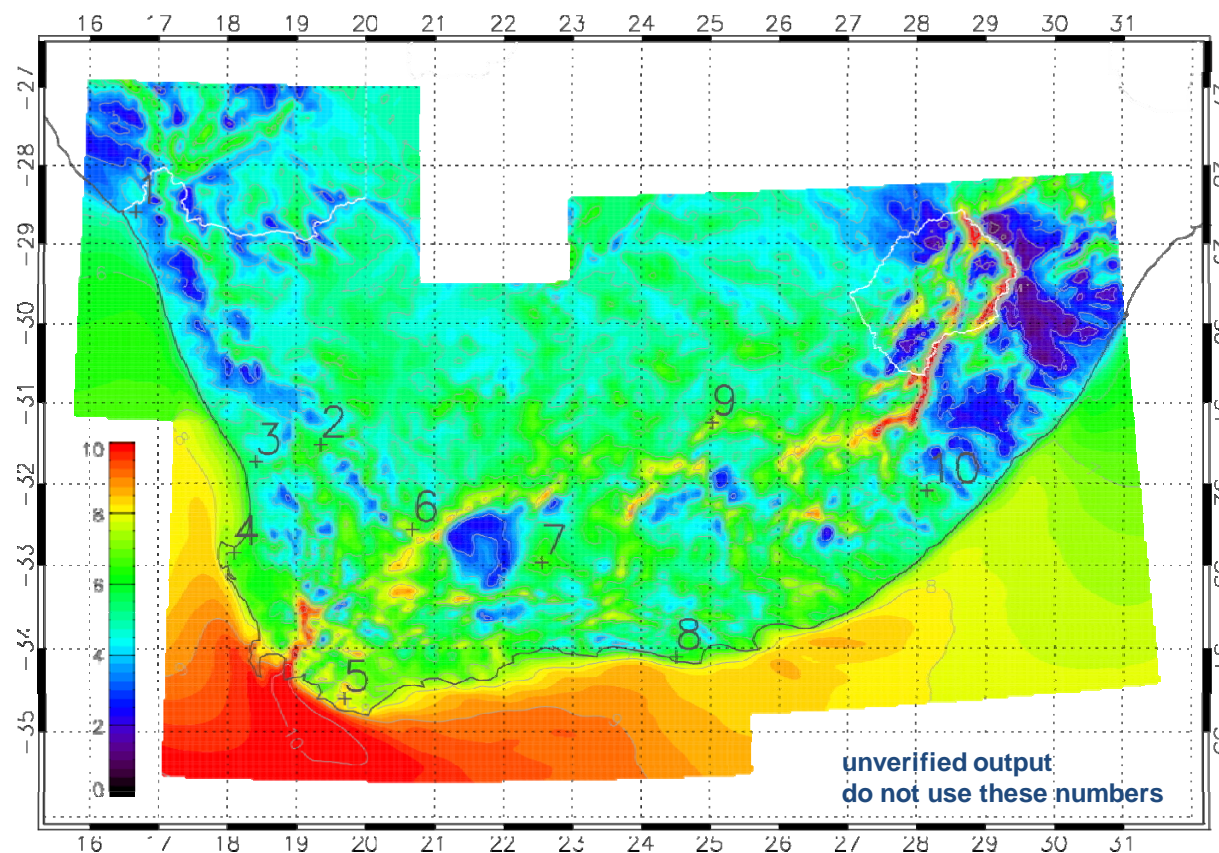
3 calculation domains

3 sets of wind classes determined by NCEP-DOE Reanalysis 2 for 1980-2009

5 km grid spacing

Elevation – SRTM30

Roughness – Land use from GLCC USGS



Preliminary comparisons with WASA data shows challenges, e.g. near WM01 and WM03

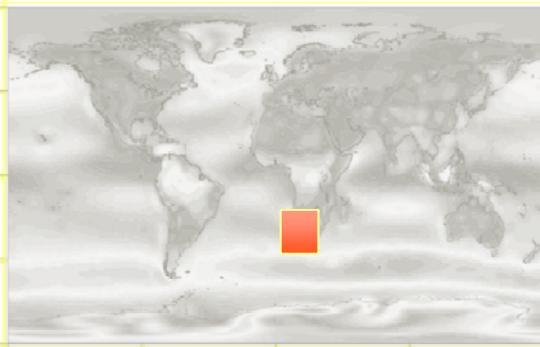
**Ongoing work: Verification, improvements and recommendations for use**

**Risø DTU**

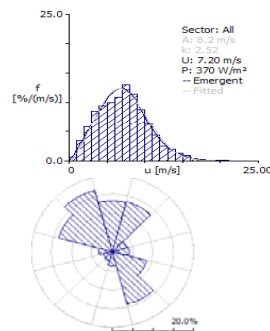
National Laboratory for Sustainable Energy

# Wind Atlas for South Africa (WASA)

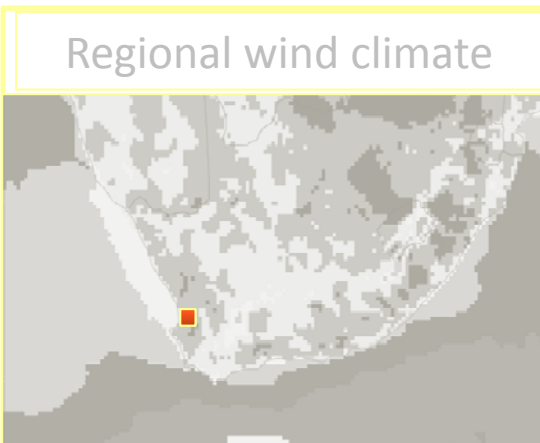
Global



Measurements



Mesoscale modeling



Microscale modeling



wind farm





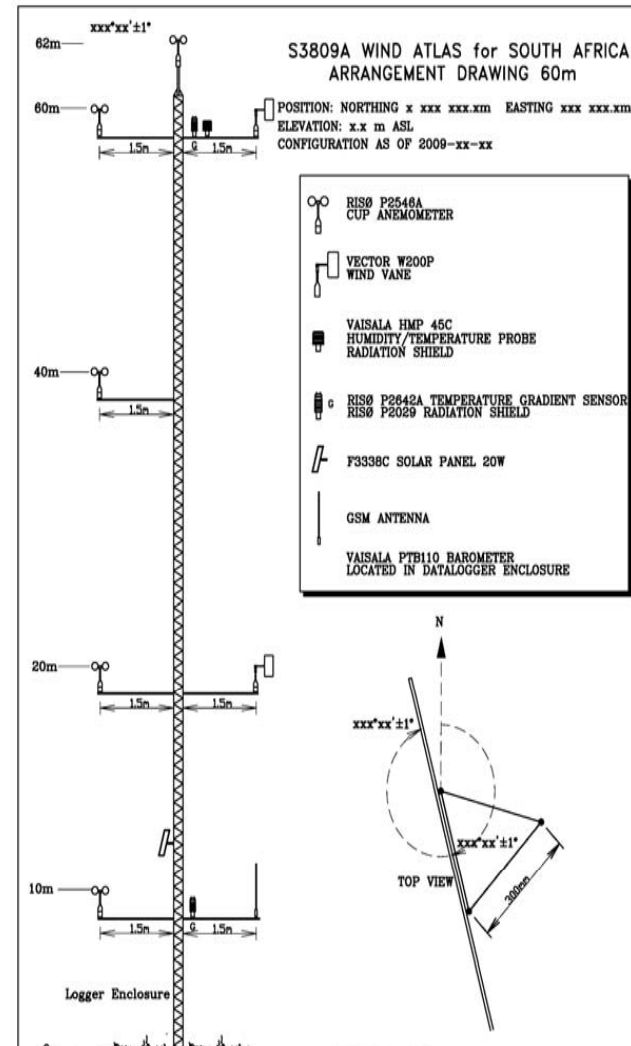
## Wind Atlas for South Africa – 10 WASA masts

10 minutes data and graphs available  
online on the project web site at CSIR:

<http://www.wasa.csir.co.za>



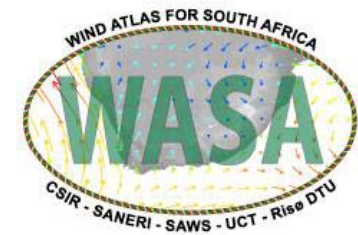
**Risø DTU**  
National Laboratory for Sustainable Energy



## Measurement progress

- First full year of data  
October 2010 – September 2011
- Station and site descriptions
- Very good data recovery
- Lessons learned will be collected

<b>WAS A</b>	<b>Data recovery (%)</b>	<b><math>U_{\text{mean}}</math> @ 61.5m (m/s)</b>
WM01	100.0	5.83
WM02	100.0	6.19
WM03	100.0	7.13
WM04	100.0	6.68
WM05	95.8	8.58
WM06	100.0	7.00
WM07	100.0	6.95
WM08	100.0	7.36
WM09	89.6	7.55
WM10	92.4	6.52



## WASA data – user statistics

- 361 users registered
- 300+ users downloaded data
- 29 Countries

- |                |                |
|----------------|----------------|
| – Australia    | – Lesotho      |
| – Belgium      | – Mozambique   |
| – Brazil       | – Namibia      |
| – Canada       | – Netherlands  |
| – China        | – Norway       |
| – Denmark      | – Pakistan     |
| – Finland      | – Portugal     |
| – France       | – South Africa |
| – Germany      | – Spain        |
| – Greece       | – Sudan        |
| – Hong Kong    | – Sweden       |
| – India        | – Switzerland  |
| – Ireland      | – UK           |
| – Italy        | – USA          |
| – Korea, South |                |

### WM05 graphs [page 1]

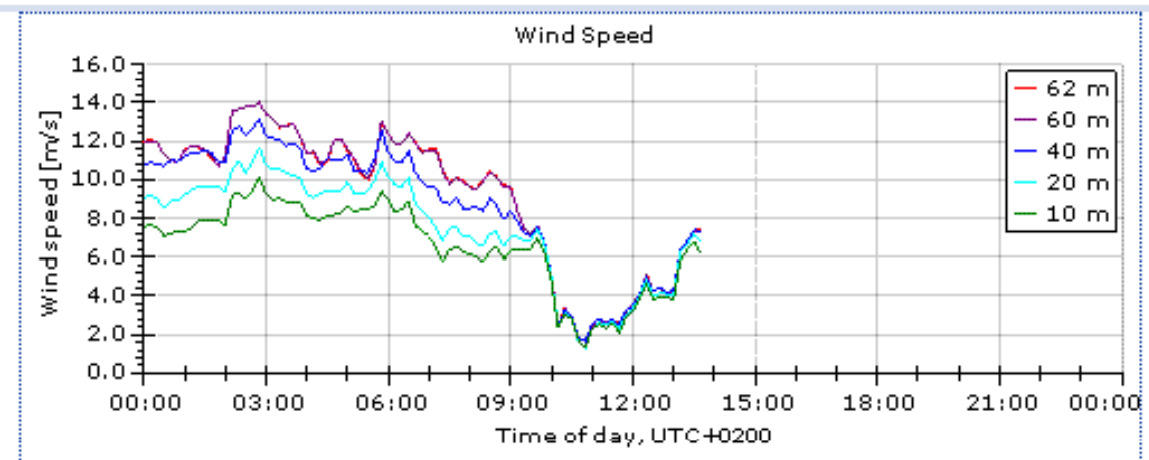
Latest update 2011-09-28 13:40:00

#### Select time period

28 ▼ September ▼ 2011 ▼

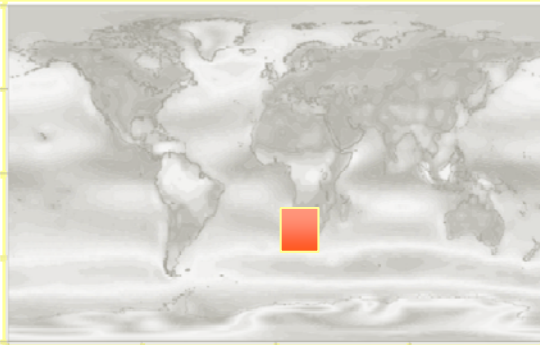
<< Previous Current Next >>

- ☒ Day  
☐ Week (Mon - Sun)  
☐ Month

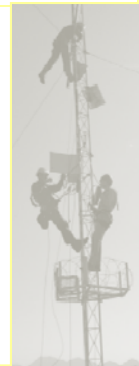
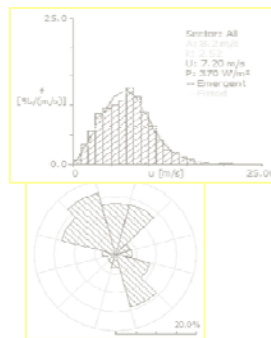


# Wind Atlas for South Africa (WASA)

Global



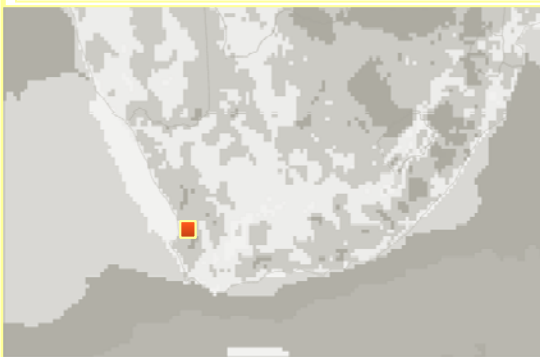
Measurements



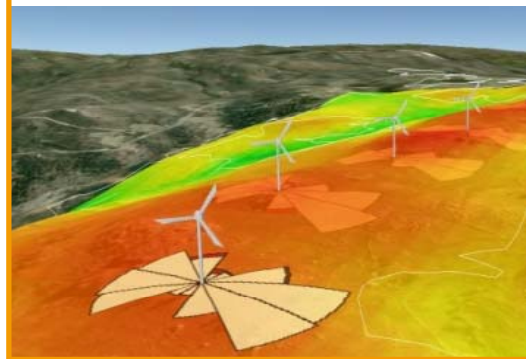
Mesoscale modeling

Microscale modeling

Regional wind climate



Local wind



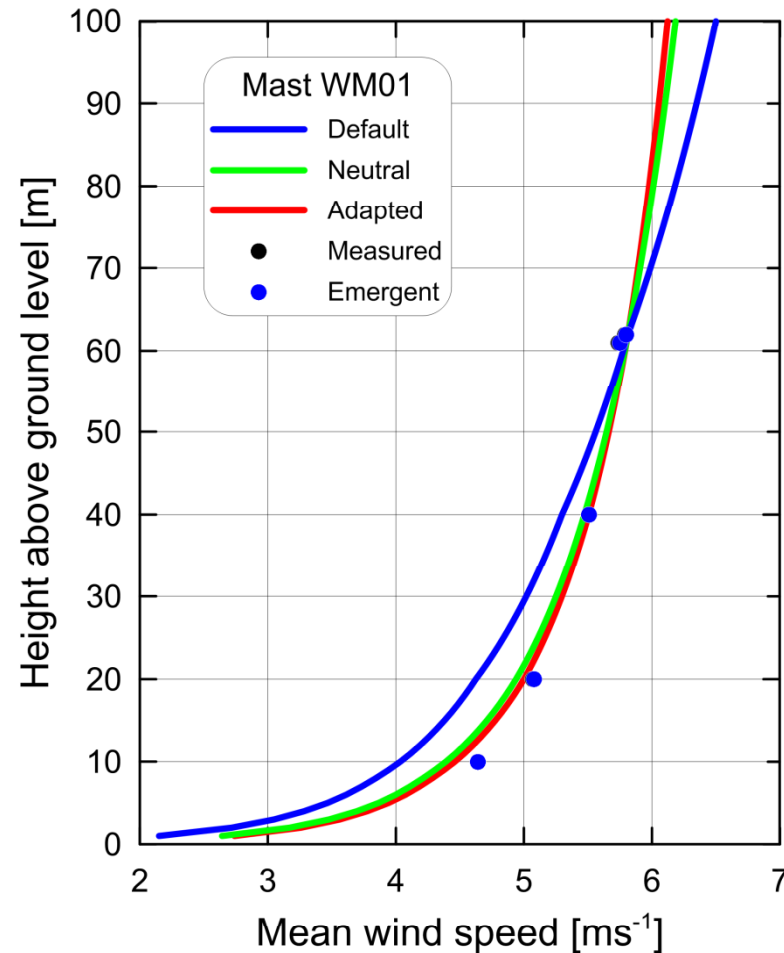
wind farm





## Microscale modelling at the 10 WASA masts shows WASA data is high quality

- Wind-climatological inputs
  - One-years-worth of wind data
  - Five levels of anemometry
- Topographical inputs
  - Elevation maps (SRTM 3 data)
  - Simple land cover maps (SWBD + Google Earth); water + land
- Preliminary results
  - Microscale modelling verification
    - Site and station inspection
    - Simple land cover classification
    - Adapted heat flux values
  - Wind atlas data sets from 10 sites





## Resource grids at 10 WASA masts

Possible at 10 sites

In public domain

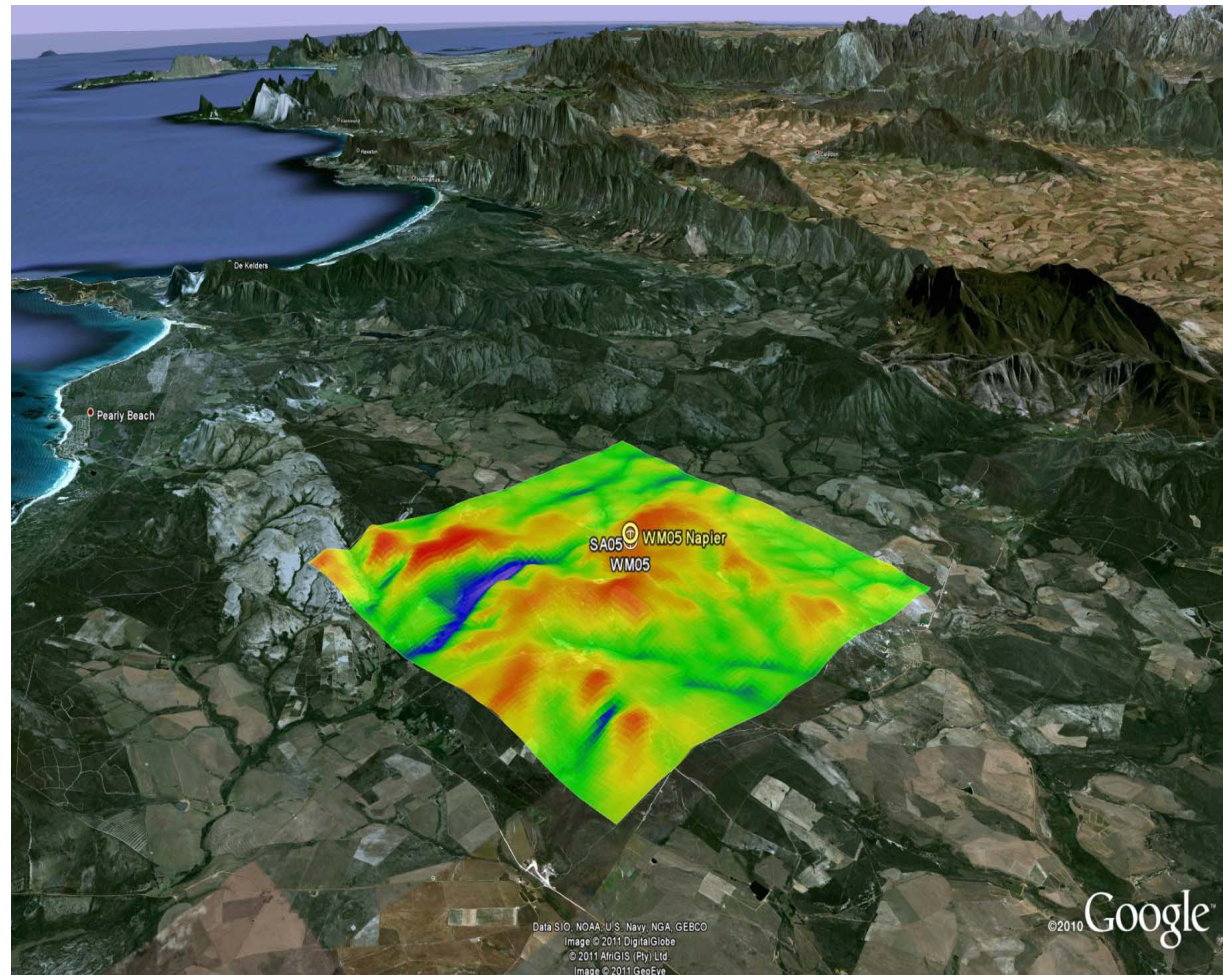
Example using WAsP at WM05

Inputs:

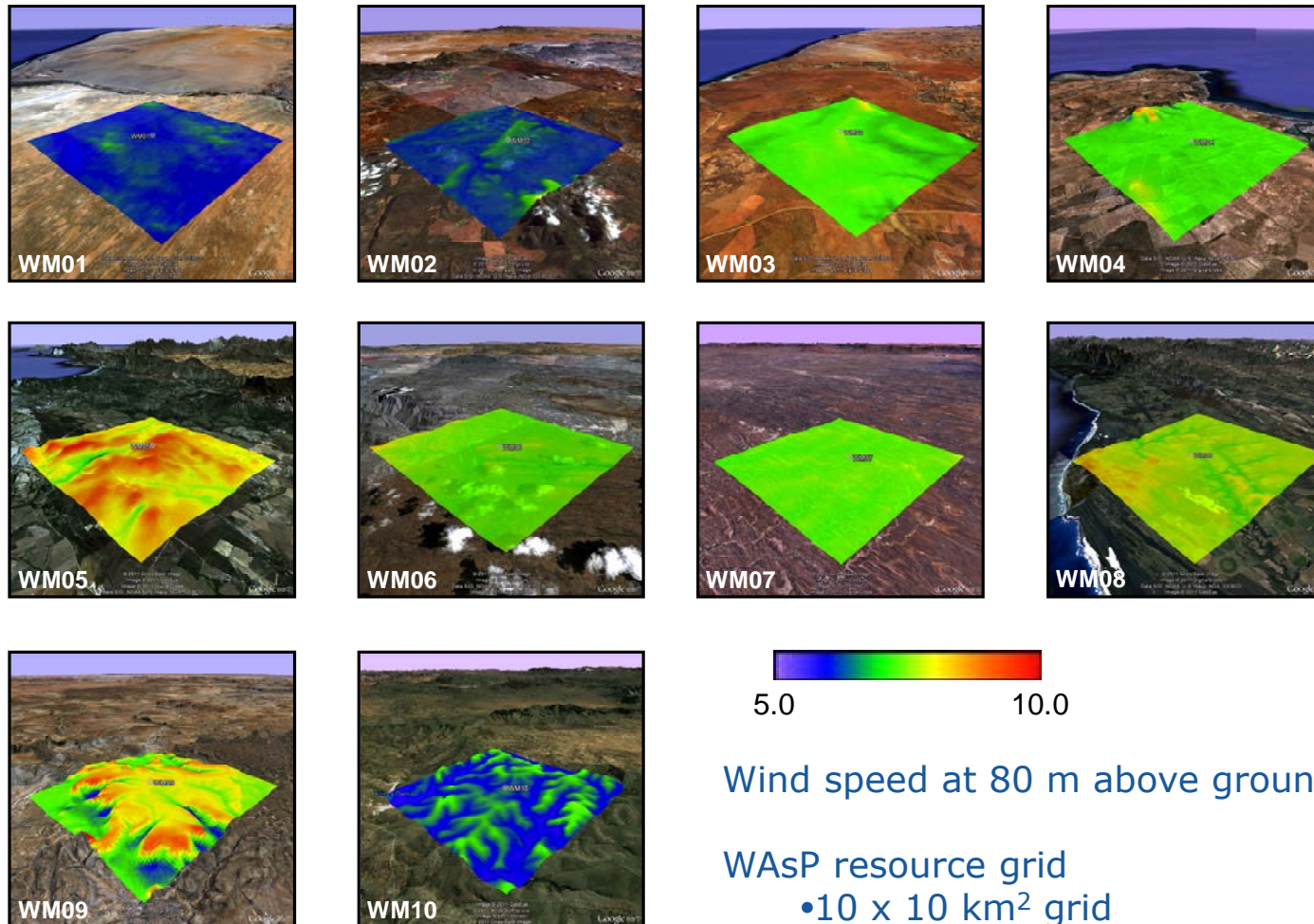
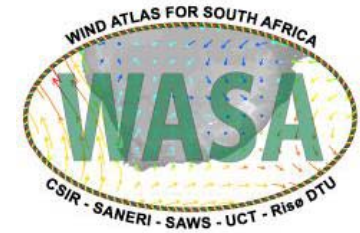
- 1-year WASA data
- WASA Station Description
- SRTM elevation map
- Google Earth roughness

Result:

- 10 km by 10 km area, 100 m grid resolution
- Annual Energy Production, AEP, of 2-MW/Ø90m wind turbine.  
 Range:  
 ■ 5.5 GWh/y to ■ 10.5 GWh/y



# Microscale WAsP modelling at 10 WASA sites from the one year of WASA data



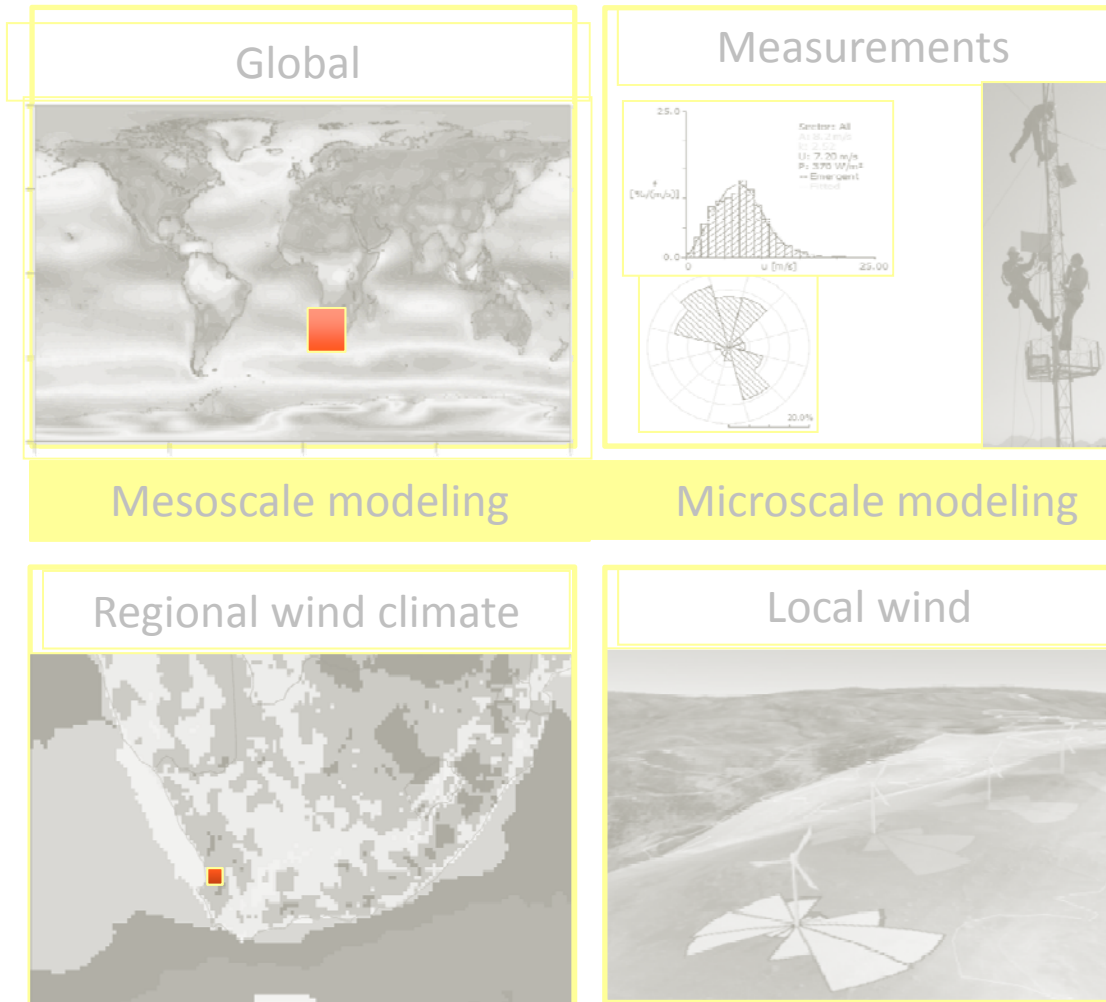
Wind speed at 80 m above ground level

WAsP resource grid

- 10 x 10 km<sup>2</sup> grid
- 100 meter grid spacing



# Wind Atlas for South Africa (WASA)



## Wind resource assessment in SA

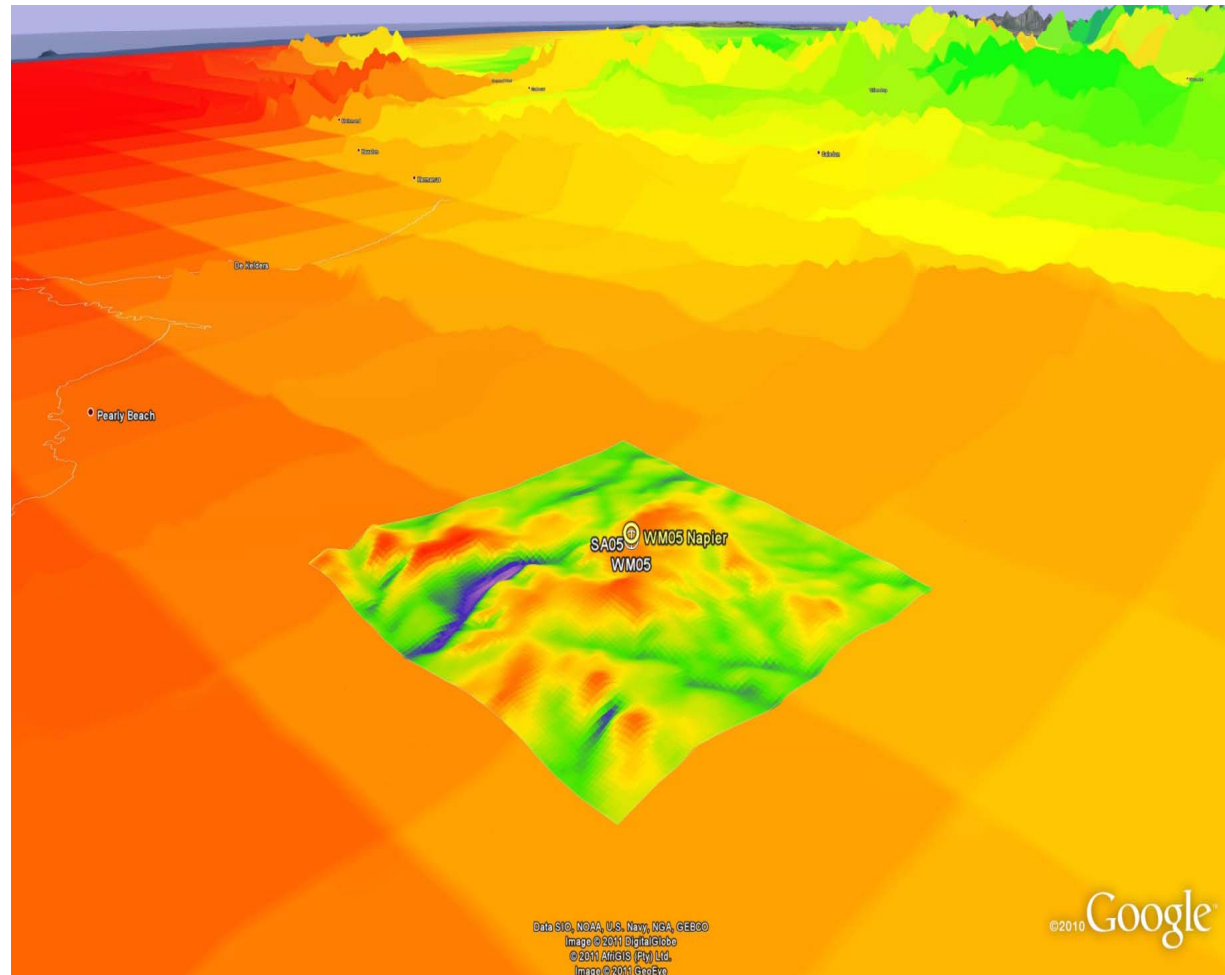
Apply the WASA mesoscale results within the project area even far from WASA masts (February 2012)

In public domain

Microscale modelling on grid of mesoscale climate provides actual wind resource, e.g. WAsP

- Input WASA wind atlas climatology
- Elevation (user defined)
- Roughness (user defined)
- Any size and resolution

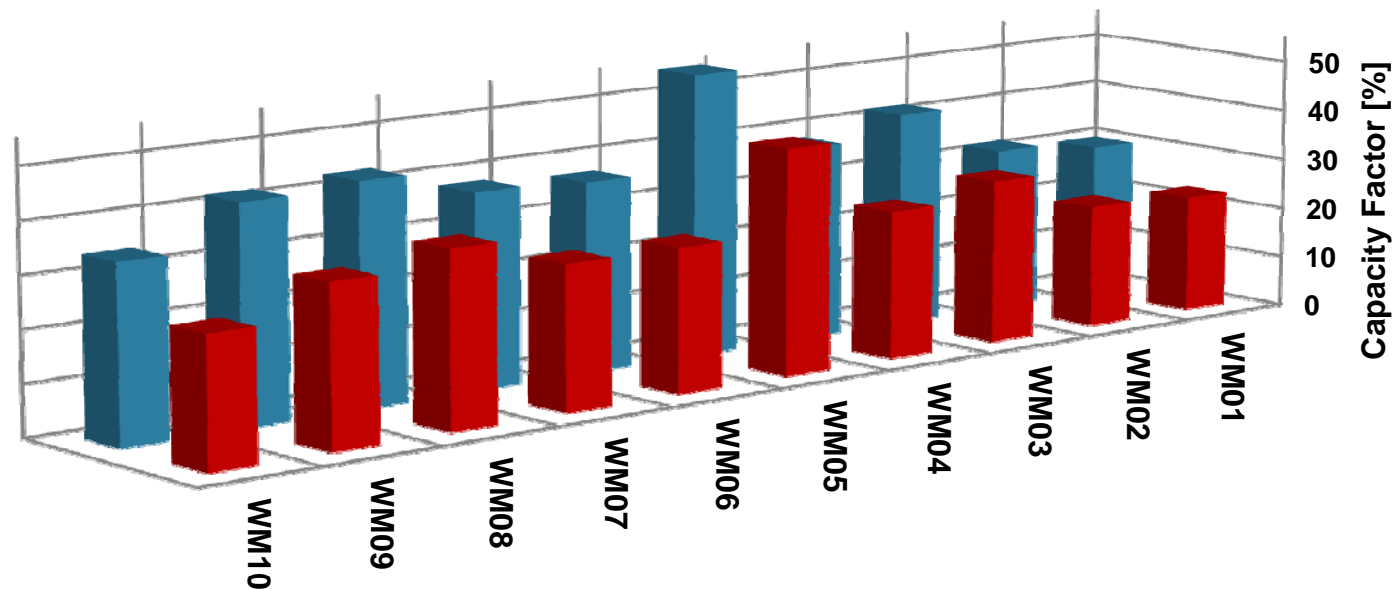
Uncertainties depend on location and terrain type



## Capacity Factors in SA

### WAsP predictions for 1 WTG on 10 WASA sites - 1 year of data

- Theoretical values, assuming 100% availability, no wakes, no losses
- Note that WASA masts are for model verification and not at windiest sites



	WM01	WM02	WM03	WM04	WM05	WM06	WM07	WM08	WM09	WM10
■ 2-MW Ø90m	30	32	42	38	55	37	38	43	42	34
■ 3-MW Ø90m	23	24	32	29	44	28	28	34	31	25

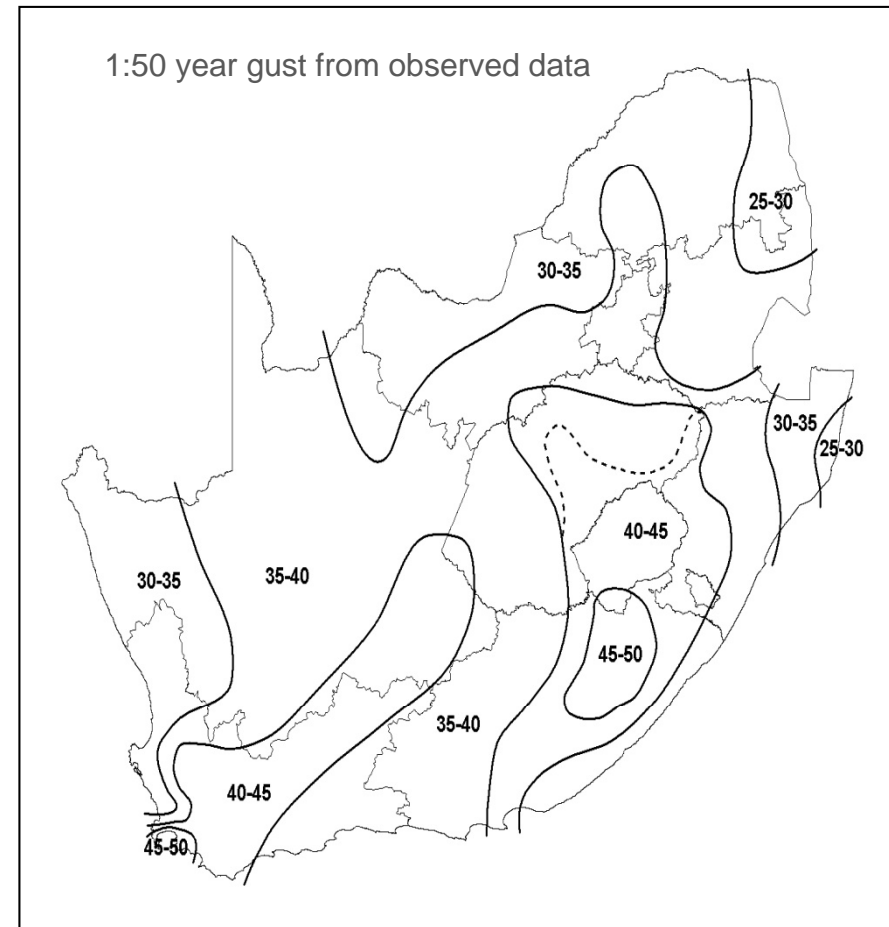
## and WASA aims to improve knowledge about Extreme wind climate

Extreme winds essential for design of wind turbines

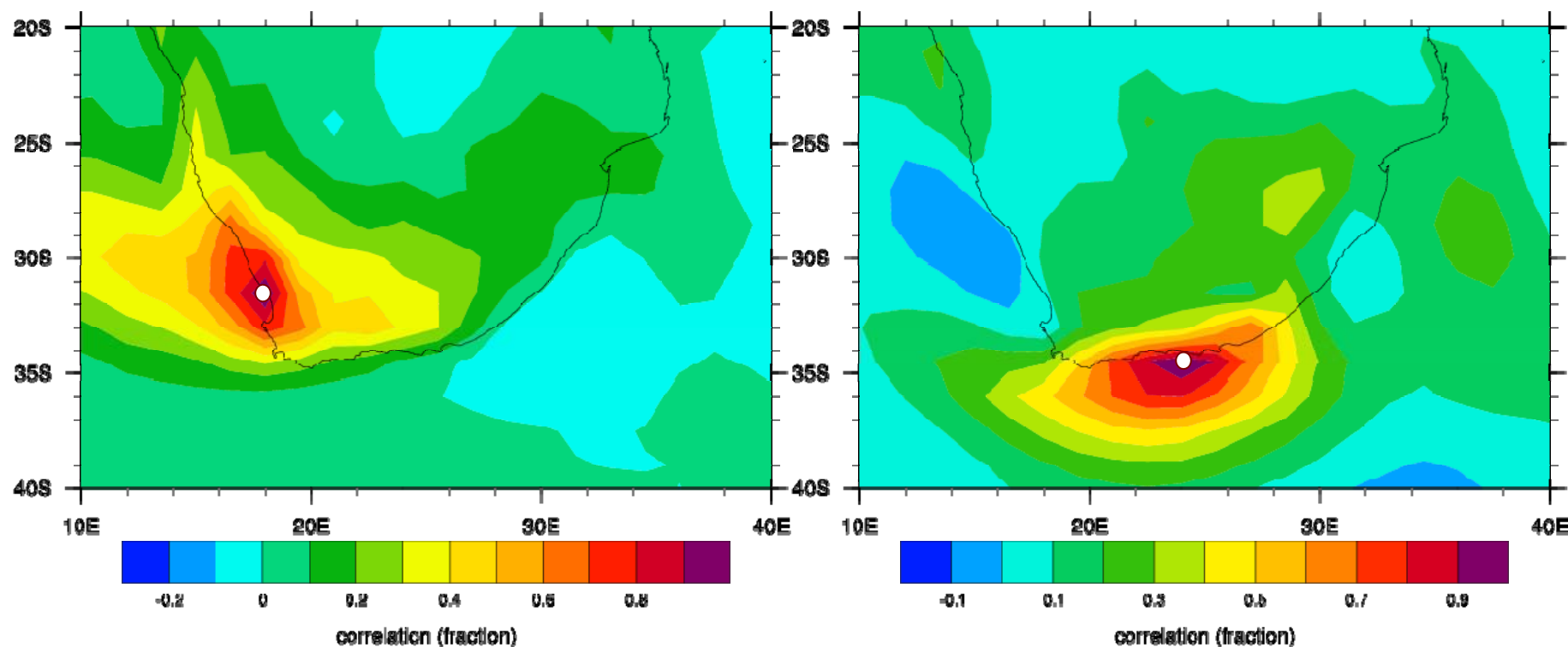
Estimations need long measuring periods and adequate density of measurements

Work in progress:

Use of WASA data and modelling



# Spatial correlations (lag 0) between 6-hourly wind speed ERA Interim Annual 1989



Wind-speed correlations in the large-scale flow.



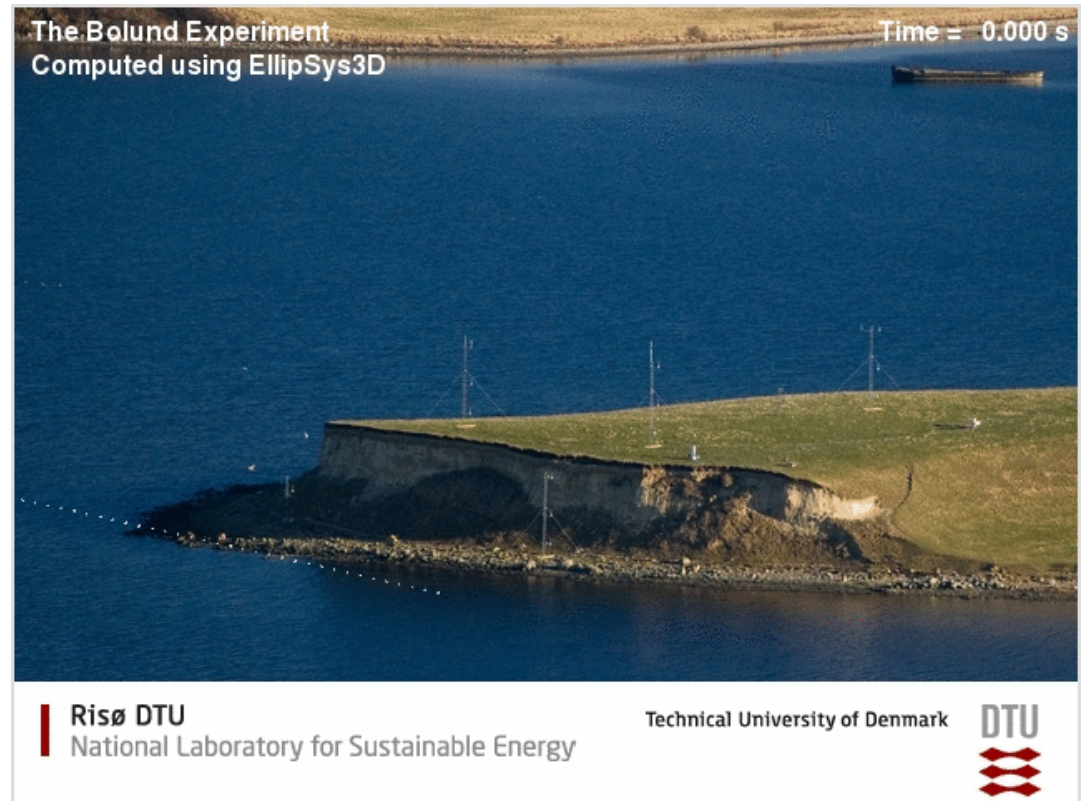
# Further research needed to drive down uncertainties

## ex: The Bolund Experiment



Blind test of flow models vs  
measurements at escarpment

Most downloads in Sept 2011 in  
Boundary-Layer Meteorology

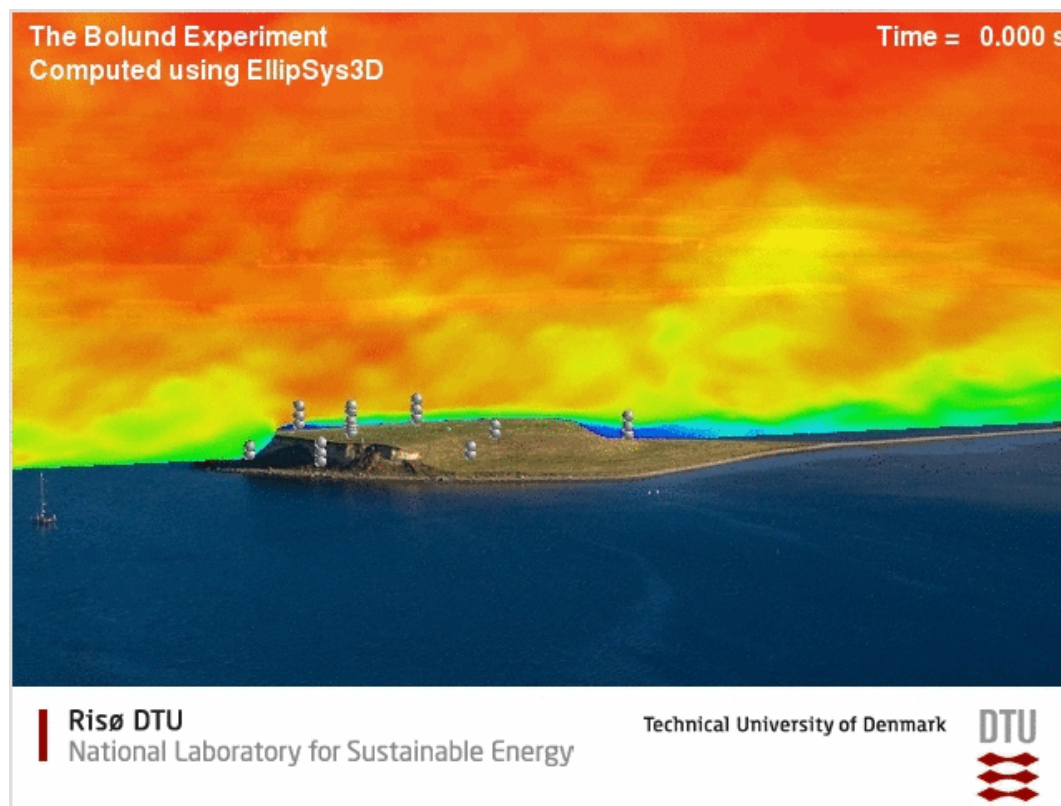




# Conclusions

## The Blind Comparison

1. Recommendation: RANS  $k-\epsilon$  is today's main workhorse, LES has not matured yet.
2. 10% error on speed-up and 20% on TKE is what to expect in complex terrain?
3. 7 diff. CFD solvers in top 10: The user is more important than the solver.



# The Bolund Experiment is thanks to

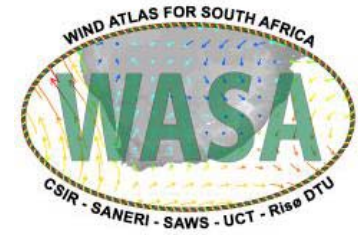
- Danish Energy Counsel
- Vestas Technology R&D
- and the 60 participating companies:

3Tier  
ANSYS  
Barlovento Recursos  
Naturales  
CENER  
CERC  
CEsA Univ Porto  
Chalmers Univ of Tech.  
COWI  
CRES  
DMI Force  
ECOFYS  
École de Technologie  
Supérieure  
EMD  
ENERCON  
EREDA  
ETH Zürich  
GAMESA  
Garrad Hassan  
GE Infrastructure  
DNV

Geo-net  
Germanischer Lloyd  
Go Virtual Nordic AB  
Kjeller Vindteknikk  
Megajoule  
Meridian Energy  
Metacomp Technologies  
Meteodyn  
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Water & Atmospheric  
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Natural Power  
NCAR  
Nordex  
Normawind  
Numeca  
RES  
ReSoft ltd  
RWE npower renewables  
Siemens Wind Power a/s  
Star-CD  
Suzlon Wind Energy

Tokyo Institute of  
Technology  
TUV Nord  
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Univ Johns Hopkins  
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Univ Nottingham  
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Vijayant Kumar  
Von Karman institute  
Wind Farm Grou  
Windlab Systems  
WindSim



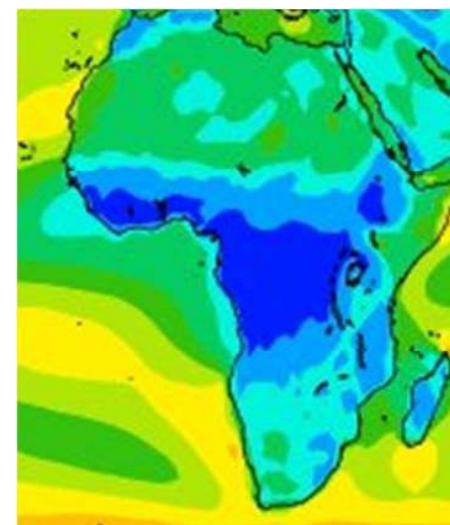


## WASA work plan

30 June 2009	Project Commencement at contract signature
March 2010	First public project workshop presenting <ul style="list-style-type: none"> <li>• Project plans, methods and tools</li> <li>• First unverified wind atlas</li> </ul>
July/Aug/Sep 2010	10 WASA measurement stations in operation
September 2010	Wind data publishing monthly on web-site activated
September 2011	1 year of data. Site and station description at the 10 WASA stations
February 2012	Midterm Workshop presenting <ul style="list-style-type: none"> <li>• First wind atlas verified against 1 year of measurements</li> </ul>
February 2014	Final Workshop and Wind Seminar presenting <ul style="list-style-type: none"> <li>• Researched wind resource atlas</li> <li>• Extreme wind atlas</li> </ul>

# Outline

- Wind mapping – the facts
- Wind Atlas for South Africa (WASA) – the case
- Africa – challenges and opportunities



## DTU

-

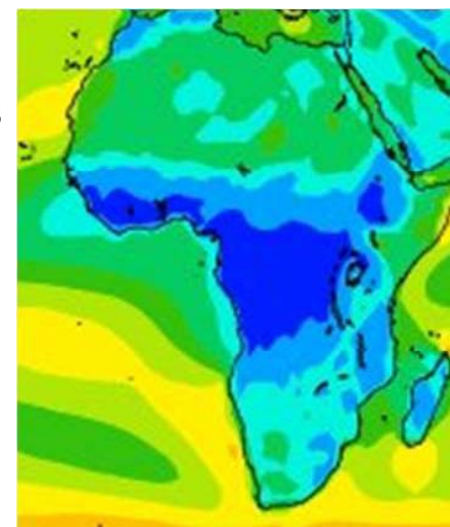
# Global Wind Atlas for policy and planning

Clean Energy Ministerial Multilateral Working Group on Solar and Wind Technologies has taken an initiative regarding a Global Wind Atlas

- For the needs of policy makers, energy planners and the Integrated Assessment Modelling (IAM) community.
- The Global Wind Atlas will provide a unified, high resolution, and public-domain dataset of wind energy resources for the whole world by 2015
- Risø DTU has developed a framework methodology for the project
  - using microscale modelling to capture small scale wind speed variability (crucial for better estimates of total wind resource), but no mesoscale modelling
  - giving comprehensive uncertainty estimates
- Results to be published the methodology to ensure transparency (peer review)
- DK government funds Risø DTU providing Denmark's contribution to the CEM Multilateral Working Group on Solar and Wind technologies implementation plan.
- Other partners at this stage:
  - International Renewable Energy Agency (IRENA)
  - CENER, Spain
  - DLR, Germany
  - NREL and NCAR, USA

## Some concluding remarks

- The Wind Atlas Method can be applied in various forms for the needs of planning, policies and development
- The national wind atlas projects made e.g. in South Africa and Egypt show benefits for planning of the development of wind energy – new areas with promising resources, geographical coverage and temporal distributions
- The Global Wind Atlas can be used to identify regions that should be further explored, for Integrated Assessment Modelling and provide more accurate aggregated wind resource data than is available today
- The Global Wind Atlas needs national Numerical Wind Atlas for verification of its results in representative selected areas
- Numerical Wind Atlas should be made for detailed planning in all regions with possible wind energy potential
- Further research is needed in a global transparent collaboration



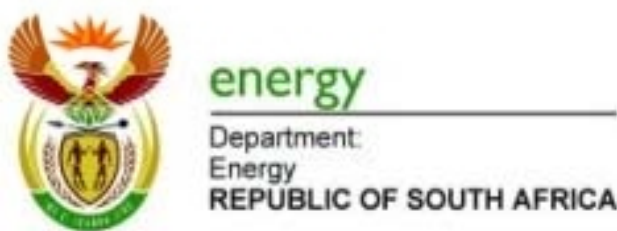
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**Thank you**